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Linking Farmer Knowledge and Learning to Agricultural Sustainability: A Study of Apple Farmers in Indonesia

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Apple farming in Indonesia is facing serious sustainability challenges. In Tutur-Pasuruan, only 20-30% of orchards remain. Despite this crisis, few studies have explored how farmers learn, build knowledge, and sustain their practices. Understanding their social learning processes is essential for developing sustainable agriculture. The research objectives were identifying farmers' learning methods, mapping key knowledge areas, and analyzing their linkages with sustainability outcomes. A transcendental phenomenological approach was used with 19 informants through in-depth interviews, observation, and documentation. Analyses were conducted using the NVivo-based Colaizzi method. The study identified 11 learning methods, with experiential (15.14%) and digital (12.12%) approaches as the most dominant. Farmers acquired knowledge in over 60 areas, grouped into nine categories, primarily related to farm management, cultivation, and soil. These learning outcomes contributed to four sustainability dimensions: social and innovation (26.5%), and economic and environmental (23.5%). The findings confirm that sustainability rests on a reflective and experiential collective learning system. This study recommends further research on integrating local knowledge with digital technology and policy design that supports the documentation and replication of farmer learning systems.

Keywords: Social learning, experiential knowledge, digital adaptation, community-based learning, local innovation systems, informal farmer networks.

INTRODUCTION

Sustainable agriculture is a crucial issue globally, given that more than 1.5 billion people depend on small-scale agriculture, which accounts for only about 4% of global GDP (Anonymous, 2021). However, conventional farming practices often lead to environmental degradation and negatively impact farmers' welfare (Šūmane *et al.*, 2018). Realising sustainability requires a learning approach that dynamically integrates local and scientific knowledge (Cahyono *et al.*, 2020, 2022; Chaudhuri *et al.*, 2021).

In this context, learning becomes a key mechanism in transforming agricultural systems. Unfortunately, farmers in various regions, including Indonesia, still face serious obstacles, such as limited access to information, weak institutional infrastructure, and psychosocial constraints (Bhuiyan and Maharjan, 2022; Emerick and Dar, 2020). Amid the dominance of top-down approaches, studies have shown that social learning, which emphasises interaction, reflection, and collective experimentation, is more effective in improving farmers' adaptive capacity (Mills *et al.*, 2017; Rowe *et al.*, 2022).

The crisis of apple farming in Tutur is characterised by declining production and crop populations (20-30% remaining) and multiple economic, ecological, and institutional pressures. The rise in input prices after the 1998 monetary crisis and the impact of the COVID-19 pandemic made apple farming increasingly unprofitable. Pest and disease infestations, such as root rot, insects, and 'nyawo' pests, cause massive tree mortality. One of the informants, Mr AR, revealed**:** "If the apples have been infested with lice, that is it. It is all ruined. It cannot be treated". On the other hand, high and erratic rainfall disrupts the flowering phase, reducing productivity and harvest success. In the market, local apples are priced out of competition with imported apples, making farmers' income less than the cost of production. Many go out of business, switching to citrus or other commodities to survive. In this context of crisis, understanding how farmers

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learn, adapt, and innovate is crucial for local agrarian sustainability. Likewise, some farmers - especially from the adaptive younger generation - continue to develop informal learning strategies through community interaction and the utilisation of digital technology. This includes using smartphones to access YouTube tutorials, farm blogs, and Google searches for scientific references related to pest control and developing organic inputs such as plant-based fertilisers and pesticides. These digital technologies do not replace local knowledge, but rather serve as complements that reinforce farmer-to-farmer learning and trial-and-error practices. This phenomenon shows that the process of social learning has the potential to become the foundation of agricultural sustainability in the midst of crisis.

Several studies confirm the effectiveness of this approach. In Kenya, farmer-researcher collaboration improves agricultural resilience (Restrepo *et al.*, 2018). In Canada, learning communities overcome the limitations of formal education (Laforge and McLachlan, 2018); in Asia and Africa, social capital and co-learning support smallholder agricultural diversification (Ambayoen *et al.*, 2024; Marinus *et al.*, 2021). Local knowledge is proving to be an important basis for adaptation and innovation (*Šūmane et al.,* 2018; Krzywoszynska, 2016).

However, studies that directly link farmers' learning methods, the knowledge systems developed, and their impact on sustainability are still very limited. Most previous research has separated these three aspects and has not explored the local context as a whole (Abera *et al.*, 2020; Nguyen *et al.*, 2021; Tama *et al.*, 2021).

This research addresses this gap by analysing how apple farmers in Tutur learn, what kind of knowledge they develop, and how this contributes to agricultural sustainability. This study is based on the theoretical framework of Social Learning (Bandura, 1971, 1989) as well as the concept of collective efficacy (Bandura, 1982, 2001), which views learning as a social process that takes shape within a landscape of cultural, ecological, and community interactions (Dooley, 2020; Fry and Thieme, 2019). The results of this research are expected to enrich the understanding of contextualised farmer learning systems and provide a basis for more participatory and sustainable agricultural interventions.

MATERIALS AND METHODS

***Research design*:** This research uses a qualitative approach with a transcendental phenomenological design (Neubauer *et al.*, 2019) to explore the essence of apple farmers' learning experiences in Tutur sub-district, Pasuruan. This approach allows researchers to explore "what" and "how" the farmers interpret the learning experience.

***Research site*:** The research site was purposively selected in Andonosari Village because it has a long history of apple cultivation since 1965, is the largest apple landowner (48.6% of the total village), and has the most farmer groups. The village is also a centre for apple suppliers to various large markets in Indonesia.

***Participant selection*:** A total of 19 informants were purposively selected, 10 of them as key informants. They covered a range of roles: community leaders, farmer youth, experienced senior farmers, labourers, self-help extension workers, and input shop owners. Participants ranged from 22 to 65 years old, with educational backgrounds from primary school to postgraduate, and farming experience between 7 and 40 years or more.

***Data collection techniques*:** Data collection was done through: (1) semi-structured guided in-depth interviews, (2) direct observation of farmers' farming activities and social interactions, and (3) documentation from secondary sources such as village monographs.

***Data validity and ethical considerations*:** Data validity was maintained through triangulation of sources and methods, as well as a process of epoche to avoid researcher bias.

***Data analysis procedure*:** Data analysis was conducted using Colaizzi's seven steps (Finlayson *et al.*, 2019), from rereading transcripts to developing essential structures and validating results with experts and independent reviewers. NVivo 12 was used in the initial coding and analysis process to identify key themes and relationships.

RESULTS

***Social learning methods used by apple farmers in running their plantation businesses*:** The social learning system of apple farmers in Tutur develops through a combination of traditional and modern methods that complement each other and are firmly rooted in real practice. Based on in-depth interviews, 11 social learning methods used by farmers in responding to technical, ecological, and social dynamics were identified (Figure 1). The most dominant method is experiential learning (15.14%), where farmers learn directly from experience through crop observation, treatment experiments, and daily interaction with the land. This method emphasises intuition and response to nature, which has long been the main source of farmers' knowledge.

Modern and digital learning (12.12%) was the second most prominent method. Modern and digital learning occurs through smartphones, online platforms, and social media. Young farmers frequently use YouTube to explore fertilization and pest management techniques, and they search specific pesticide active ingredients on Google based on observed symptoms. Some have adopted digital pH meters to optimize fertilizer application. WhatsApp groups function as informal discussion spaces for market prices and weather

updates and as personal channels for peer-to-peer knowledge exchange between farmers.

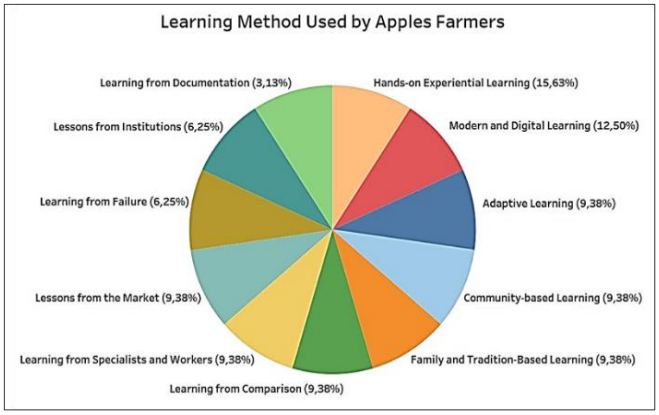

Figure 1. Learning method used by Apple Farmers.

Additionally, several farmers use Google to search for research articles and technical references to support the development of their organic formulations. Mr. AM explained: "On YouTube, it is the same as looking for references on Google. But not one reference. One reference, then I will try out what works first". He also added that some ingredients, such as tobacco and "empon-empon" (various types of medicinal rhizome plants), were obtained from online references: "Actually, there is a book, but now just look on Google".

These digital channels function not as replacements, but as complements to existing learning practices such as trial-and-error and local knowledge sharing, thereby enriching the learning ecosystem, particularly in the face of agrarian uncertainty and limited institutional support.

Meanwhile, six other methods are equally weighted (9.38% each), including adaptive learning that relies on crop yield evaluation and climate to regulate treatment; community-based informal learning through coffee shop chats and socio-religious activities; family-based learning that is passed down between generations; comparative learning from observing other farms or comparative studies; learning from specialists such as labourers and input sellers; and reflective learning from failures, both personal and others' experiences.

The other two methods have lower contributions, namely institutional learning (6.25%), which is more administrative than technical, and documentation-based learning (3.13%), which includes recording treatments and yields by a small number of progressive farmers. Interestingly, the farmers did not rely on a single method, but developed a flexible, contextualised, and adaptive social learning system, emphasizing informal interaction, experience, and reflective exploration.

This finding confirms that the main learning spaces develop outside formal institutions. Therefore, farmer empowerment strategies need to rely on strengthening social learning systems that have grown organically, instead of replacing them through top-down approaches that are insensitive to community realities.

***Knowledge areas mastered by apple farmers in managing their orchards*:** Apple farmers in Tutur develop a broad and deep spectrum of knowledge through a social learning system based on experience, exploration, and collective dialogue. Over 60 knowledge areas were identified and grouped into nine main categories (Figure 2). The top three most mastered categories, at 15.87% each, include farm management, cultivation practices, and nutrient and soil management. On the farm management aspect, farmers show proficiency in designing the cultivation cycle, evaluating efficiency, and adjusting strategies without relying on formal records. While in cultivation practices, technical activities such as pruning ("mrithil"), watering, fertilising, and thinning are done reflectively based on direct observation of crop responses. Farmers adaptively mix organic and inorganic fertilisers in nutrient and soil management, relying on intuition and natural indicators.

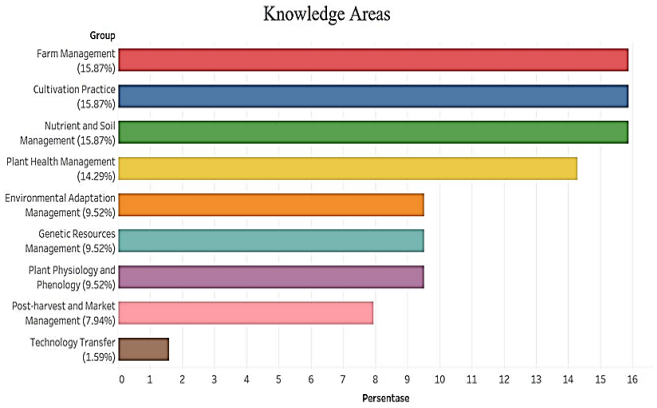

Figure 2. Proportion of knowledge areas mastered by apple farmers in managing their orchards.

In addition, knowledge on plant pest and disease control (plant health management, 14.29%) is developed through collective experience and memory, rather than standardised procedures. The ability to adapt to changes in weather and microclimate is reflected in the environmental adaptation management category (9.52%), indicating high ecological awareness. Knowledge of genetic resources and plant physiology, including propagation techniques and flowering cycles, also accounted for a significant portion (9.52% each), reflecting farmers' understanding of local varietal characteristics.

Meanwhile, downstream aspects such as post-harvest and market management only account for 7.94%, indicating that marketing knowledge is still limited and centred on local networks. The category with the lowest proportion is

technology transfer (1.59%), indicating the low integration of technology and formal training in their learning system.

This distribution confirms that apple farmers' main strength lies in their technical and ecological mastery, which is built on direct experience and social interaction. However, low access to institutional information and modern technology indicates a structural gap. As per the findings of Šūmane *et al.* (2018) and Krzywoszynska (2016), Farmers' knowledge systems are the result of social constructions that grow in cultural and ecological landscapes. Therefore, strengthening farmers' capacity must honour these local knowledge systems, not replace them with technocratic approaches that are detached from field realities.

***The impact of apple cultivation practices on sustainability outcomes at the farm level*:** The apple cultivation practices in Tutur were established through social learning and contribute significantly to four key aspects of sustainability: social, innovation, economic, and environmental (Figure 3). Social and innovation aspects recorded the highest impact (26.5% each). On the social side, farmer learning resulted in changes in community interaction patterns, strengthened social cohesion, and encouraged the regeneration of young farmers. However, challenges such as declining social capital and shifting farmer groups persisted. Cultural adaptation and management of social relations are key in maintaining community identity and local public health.

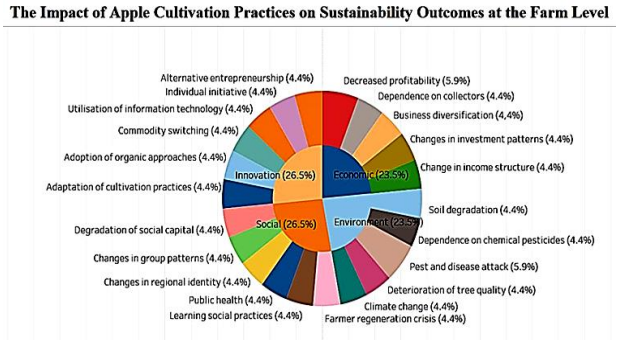

Figure 3. Impact of apple cultivation practices on sustainability outcomes at the farm level.

The innovation dimension emerges from farmer initiatives born from experimentation, failure, and informal knowledge exchange, not from formal training. These innovations include business diversification, using simple digital technologies, and changes in cultivation approaches that suit local conditions. This confirms that innovation in apple farming is not the result of technology transfer, but rather the product of a reflective and responsive learning system. For example, some young farmers concoct their own bio-organic fertiliser based on PGPR and plant-based ingredients. Others are experimenting with active ingredient-based spray schedules based on Google references. One informant (Mr AM) mentioned concocting pesticides from neem and tobacco leaves after comparing various online sources and testing them in the field.

The economic aspect contributes 23.5%, reflecting how farmers' learning affects their income structure and business diversification strategies. However, challenges such as dependence on middlemen, investment fluctuations, and limited market access limit the achievement of long-term profitability. Farmers demonstrate adaptive capacity in responding to economic pressures by adjusting farming strategies based on experience.

Environmental aspects contribute 23.5% to sustainability, although ecological pressures such as soil degradation, pest infestation, and reliance on chemical pesticides remain high. Some farmers have adopted experience-based conservation practices, but the lack of systemic interventions limits the effectiveness of these efforts. Micro-ecosystem imbalance is a significant challenge that has yet to be fully addressed.

The sustainability outcomes found in this study are closely linked to specific knowledge areas developed through farmers' local learning. For example, knowledge of nutrient and soil management (15.87%) contributes to environmental sustainability through reducing soil degradation and optimising fertiliser use. Knowledge of farm management and cultivation techniques, such as pruning, thinning, and seasonal scheduling, strengthens economics by increasing yield efficiency and controlling costs. On the social side, intergenerational knowledge transfer and community-based learning strengthen cohesion and collective action, which underpin the sustainability of farmer groups and their social identity as farmers. Meanwhile, informal experimentation and adaptive pest control strategies reflect the contribution of innovative knowledge, enabling farmers to respond to climate variability and pest resistance, often unaccommodated by the formal extension system. These linkages emphasise that sustainability is not a generic outcome of agricultural practices but a function of contextualised knowledge systems that grow from farmers' learning processes.

The relatively balanced distribution of impacts among the four aspects suggests that the sustainability of apple cultivation is supported by different contributions from each dimension: social, innovation, environmental, and economic. In this study, all four were analysed separately and stand-alone, as explained in the description of the results and shown in Figure 3. Social aspects include community cohesion and farmer regeneration, while innovation refers to new practices that emerge from experimentation and reflective learning. Environmental aspects relate to adaptation to micro-ecosystem changes, pest management, and experience-based fertilisation. Meanwhile, economic aspects include farm diversification strategies, production input adjustments, and adapting to market pressures. This separation thus clarifies the role of each dimension in comprehensively shaping sustainability.

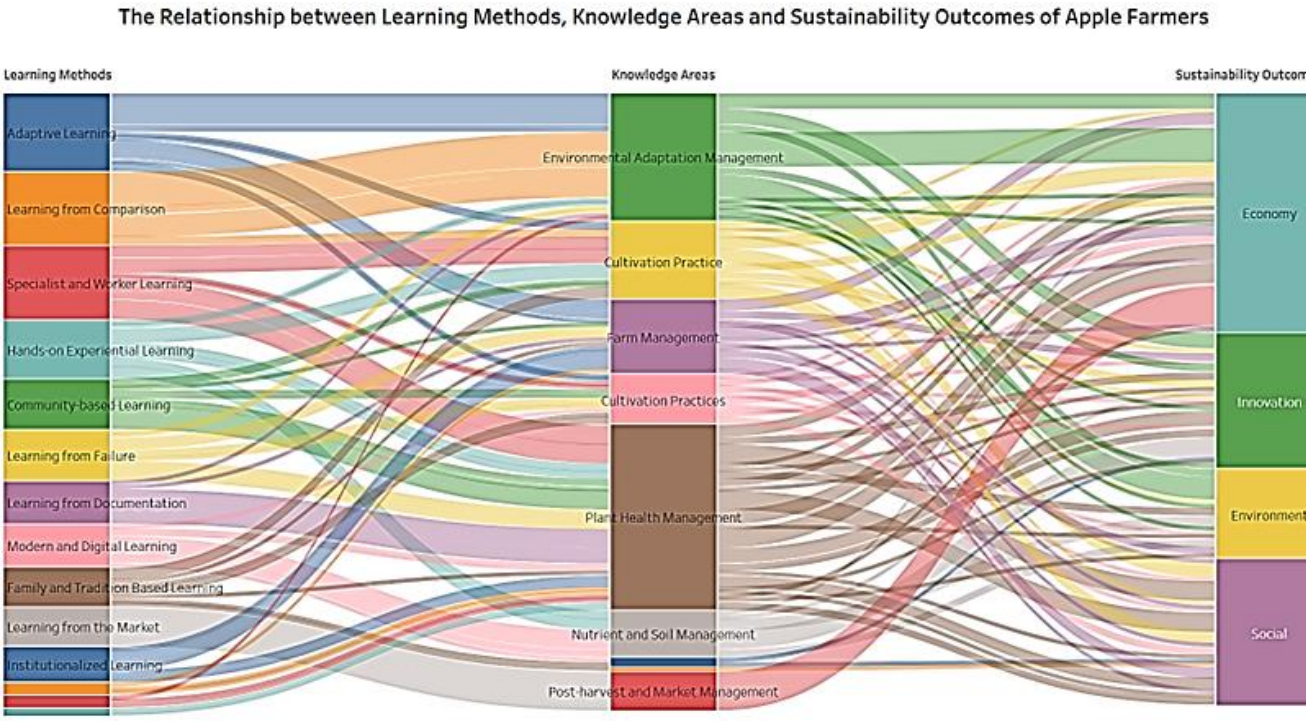

Figure 4. Understanding the complex relationship between learning methods, knowledge areas, and apple farmers' sustainability outcomes.

***The relationship between learning methods, knowledge areas, and sustainability outcomes of apple farmers*:** Analysis of the linkages between learning methods, knowledge areas, and sustainability outcomes shows that the learning system of apple farmers in Tutur is complex, dynamic, and interconnected. There is no linear one-to-one relationship between methods, knowledge, and outcomes, but rather a flexible multidirectional network pattern (conceptually see Figure 4). Farmers use different combinations of methods to build diverse knowledge, resulting in sustainability impacts on multiple dimensions.

The most widely contributed methods are adaptive learning, hands-on experiential learning, and community-based learning. They are instrumental in developing core knowledge such as farm management, cultivation practices, plant health management, and nutrient and soil management. Meanwhile, methods such as learning from failure and comparative learning are important sources of innovation and customisation of cultivation practices.

The three most central knowledge areas - cultivation practices, farm management, and environmental adaptation management - act as nodes that connect methods with more than one dimension of sustainability. For example, adaptive learning that generates cultivation knowledge contributes to innovation and economic sustainability, while experiential learning through farm management simultaneously impacts economic, social, and environmental aspects.

Each sustainability dimension receives contributions from different combinations. Economic sustainability is strengthened by managerial and post-harvest knowledge. Environmental sustainability comes from ecological adaptation and nutrient management. In contrast, social sustainability evolves from regeneration processes, collective learning, and social cohesion supported by family and community-based learning. Innovation, as the most flexible outcome, emerges from reflection, experimentation, and comparison methods.

However, not all methods contribute equally. Institutionalised learning and documentation-based learning had a limited scope of impact, suggesting that sustainability is determined by the type of method, the depth of practice, and its linkage to real-life experiences. This finding confirms that the success of apple farming systems does not come from isolated technical interventions, but rather from the integration of cross-elements in a living social learning system rooted in local realities.

DISCUSSION

The results show that the apple farmers' learning system in Tutur is diverse and forms a vibrant and adaptive social network. The eleven social learning methods identified - dominated by experiential learning (15.14%) and digital-modern learning (12.12%) - indicate that the learning process

is not one-way but occurs through observation, experimentation, reflection, and exchange between individuals. This finding answers the main objective of the study: how social learning methods contribute to farmers' knowledge development and farming system sustainability.

Nine knowledge categories with more than 60 specific topics were identified, mainly related to farm management, cultivation practices, and soil and nutrient management. These results show that apple farmers have a strong technical and ecological knowledge base, built through non-formal learning and accumulated across generations. The integration of learning methods and knowledge contributes significantly to sustainability, especially in the social (26.5%) and innovation (26.5%) dimensions, followed by economic and environmental (23.5% each). This shows that the farmers' learning process targets productivity and creates space for social regeneration and adaptive innovation.

This finding is in line with previous literature. Šūmane *et al.* (2018) and Krzywoszynska (2016) emphasise that farmers' knowledge is a social construction born out of practice, not simply the result of technology transfer. Ambayoen *et al.* (2024), Yuliati *et al.*, 2024, and Chaudhuri *et al.* (2021) also confirmed that community-based learning increases farmers' resilience to external pressures. The research findings also emphasise the importance of a learning system that can integrate local and scientific knowledge in a dynamically sustainable manner (Cahyono, 2019). However, this study makes a novel contribution by directly and integratively linking learning methods, knowledge areas, and sustainability outcomes. This novelty reinforces the importance of learning systems analysis as a foundation for sustainable interventions in the location-specific agriculture sector.

From a theoretical perspective, these results affirm the principle of Social Learning Theory, which states that learning occurs through a reciprocal relationship between the individual, behaviour, and environment (Clark and Zimmerman, 1990; Bandura, 1989; Abdullah, 2019). The process of observation, imitation, and reflection by farmers, both individually and collectively, forms a learning system that encourages collective efficacy (Bandura, 1982; 2001). This collective efficacy has proven crucial in sustaining local innovations and community solidarity in apple farming, which is undergoing an ecological and demographic crisis.

Social Learning Theory (Bandura, 1971; 1989) is evident in the daily practices of apple farmers in Tutur. Observations are visible in the way farmers observe pruning techniques, flowering arrangements, and plant responses to specific treatments. Imitation is seen when they copy "Mrithil" techniques, the use of PGPR, or plant-based pesticide formulas that have proven successful in neighbouring fields. Reflection comes when farmers evaluate crop failures or pest attacks and try new approaches based on discussions and digital reference searches. Some farmers stated that they compare information from YouTube or Google, then try out what suits their fields. Meanwhile, reciprocal determinism is reflected in the mutual interaction between personal beliefs (trusting in friends' experiences), actions (trialling new methods), and the social-ecological environment (rainfall, diseases, market dynamics). This finding reinforces that farmers' learning process is closely aligned with the core principles of Social Learning Theory, and is an important foundation in building contextualised knowledge-based sustainability.

Through self-regulation capacities, apple growers set goals, control their behaviour, and assess progress against the standards they set, resulting in sustainable behaviour change (Bandura, 1991; Clark and Zimmerman, 1990). This finding also confirms that in apple farming practices, social learning is formed through complex social and cultural processes (Dooley, 2020; Fry and Thieme, 2019).

This finding implies that agricultural policy cannot simply focus on technical extension and input subsidy programmes. Effective interventions must open up spaces for reflective learning, strengthen horizontal networks between farmers, and support the documentation and exchange of knowledge locally. The failure of the conventional institutional approach is evident from the low contribution of institutional learning (3.13%) to sustainability. This indicates the need for a paradigm shift towards participatory facilitation and context-based co-learning.

Some unexpected results also emerged. One of these was the high proportion of innovations (26.5%) that emerged without formal institutional backing. The innovations do not come from training or projects, but from experiments, failures, and community discussions. This reinforces the idea that innovation is not merely a product of technology, but the result of informally organised social processes.

Transcendental phenomenological methodology proved appropriate to explore the meaning of farmers' learning experiences in depth. However, limitations remain, such as the reliance on subjective narratives and the limited number of informants (n=19), which cannot be statistically generalised. Validity has been maintained through triangulation and epoche, but results must be confirmed in a broader and more diverse context.

Finally, this research opens up opportunities for further exploration. Firstly, how does this social learning system survive or change in the context of generational change and migration of young farmers? Secondly, how can the relationship between local knowledge and digital technology be synergised to expand sustainability impacts? Third, what are the strategies for documenting and replicating these informal knowledge systems so that they can be supported through evidence-based policies?

***Conclusion*:** This research shows that the social learning system of apple farmers in Tutur is adaptive, collective, and experience-based. Farmers use various learning methods to

build core knowledge around orchard management, cultivation practices, and ecological conservation. The results impact four dimensions of sustainability equally: social and innovation (26.5%) and economic and environmental (23.5%), signalling that sustainability grows from the learning power of communities, not just from outside technical interventions.

This study makes an important conceptual contribution to strengthening Social Learning Theory in the context of location-specific agriculture. The findings show that farmers' learning process takes place not only through observation or imitation but also through collective reflection, productive failure, and improvisation of praxis. The approach integrates methods, knowledge, and sustainability into a living-learning system. It enriches the theoretical framework by adding collective efficacy and community adaptive capacity dimensions as key determinants of locally-based sustainability.

Practically, these findings indicate the importance of agricultural policies that not only focus on technical extension and input subsidies but also open up spaces for reflective learning, strengthen horizontal networks between farmers, and support the documentation and exchange of local knowledge.

Although this study is limited to one area with a relatively small number of informants, the results open up opportunities for further research that is more extensive and in-depth. Future strategic directions include studies on the resilience of social learning systems amidst farmer regeneration and rural transformation. Further research is needed to identify barriers and drivers in integrating local knowledge with digital technology, especially in limited resources. In addition, there is a need to explore further specific and applicable policy mechanisms to support farmer-led learning systems, such as strengthening local institutions, incentivising farmer innovations, and integrating participatory approaches in extension programmes and knowledge exchange.

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***Consent for publication*:** All authors submitted consent to publish this research article in JGIAS.

***Data availability statement*:** The data presented in this study are available on request from Suryaman Sule. The data are not publicly available due to ethical reasons.

***Conflicts of interest*:** The authors declare no conflicts of interest. The funders had no role in the study's design, data collection, analysis, interpretation, manuscript writing, or decision to publish the results.

***Informed consent*:** Written informed consent was obtained from all participants regarding publishing their data and photographs.

***SDGs addressed*:** No Poverty, Zero Hunger, Quality Education, Decent Work and Economic Growth, Responsible Consumption and Production, Climate Action, Life on Land.

***Policy referred*:** Indonesia's National Agricultural Policy (Kementerian Pertanian / Ministry of Agriculture), Indonesian Digital Agriculture Strategy (Agenda Pertanian 4.0).

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